Chapter 5
Concrete Culverts

5-1. Features Affecting Structure Shape and Capacity

The following information applies to the design of reinforced concrete culverts. Typical conduit shapes used for culverts are shown in Figure 5-1.

a. Location. Ideally, the axis of a culvert should coincide with that of the natural streambed and the structure should be straight and short. This may require modification of the culvert alignment and grade. Often it is more practical to construct the culvert at right angles to the roadway. However, the cost of any change in stream channel location required to accomplish this should be balanced against the cost of a skewed alignment of the culvert, and changes in channel hydraulics should be considered.

b. Grade and camber. The culvert invert gradient should be the same as the natural streambed to minimize erosion and silting problems. Foundation settlement should be countered by cambering the culvert to ensure positive drainage.

c. Entrance and outlet conditions. It is often necessary to enlarge the natural channel a considerable distance downstream of the culvert to prevent backwater from entering the culvert. Also, enlargement of the culvert entrance may be required to prevent ponding above the culvert entrance. The entrance and outlet conditions of the culvert structure directly impact its hydraulic capacity. Rounding or beveling the entrance corners increases the hydraulic capacity, especially for short culverts of small cross section. Scour problems can occur when abrupt changes are made to the streambed flow line at the entrance or outlet of the culvert.

5-2. Materials

Table 5-1 lists the applicable standards for the materials used in the design of reinforced concrete culverts.

5-3. Installation

a. Foundation material. Materials to be used for the culvert pipe foundation should be indicated on the drawings. Refer to the geotechnical foundation report for the project.

b. Bedding materials. Bedding class and materials for culverts should be indicated on the drawings. Beddings shown in the American Concrete Pipe Association's *Concrete Pipe Design Manual* (1992) are acceptable. When designing the bedding for a box culvert, assume the bedding material to be slightly yielding, and that a uniform support pressure develops under the box section.

5-4. Loadings

Assume that design loads for concrete culvert pipe are calculated as vertical pressures and that the horizontal pressures are controlled by the backfill requirements. Refer to Chapter 2 for typical loading calculations. Concentrated live loads for highway or railroad loadings should be applied as required by the standards of the affected authority and in accordance with Chapter 2 of this manual.

a. Railroad, highway, and aircraft loads. Culverts designed for loadings from railroads, highways, or aircraft need to satisfy the criteria of the affected authority. This manual presents data closely related to the requirements of the American Railway Engineering Association (AREA) (1996) and the American Association of State Highway Transportation Officials (AASHTO) *Standard Specifications for Highway Bridges* (AASHTO 1996). The method used to combine wheel live loads and earth loads on culverts is shown in Figure 5-2. The procedure presented in the *Concrete Pipe Design Manual* (American Concrete Pipe Association 1992) should be used to distribute aircraft wheel loads through pavement slabs to the top of the culvert. Railroad or highway loads may be ignored when the induced vertical stress fields are equal to or less than 4.8 kPa (100 psf), a depth of 2.4 m (8 ft) for highway loadings, or 9 m (30 ft) for railroad loadings. Note that the railroad and highway loads as shown are in accordance with ASTM A 796 and include an impact factor of 50 percent, which is higher than the impact loads required by AREA or AASHTO criteria.

b. Special point loads. Pressure bulb charts are acceptable for determining the nominal vertical stress fields from relatively small footings. Pressure bulbs for continuous and circular/square footings are shown in Figures 5-3 and 5-4, respectively. Consult a geotechnical engineer for lateral loads from surface surcharge loadings.

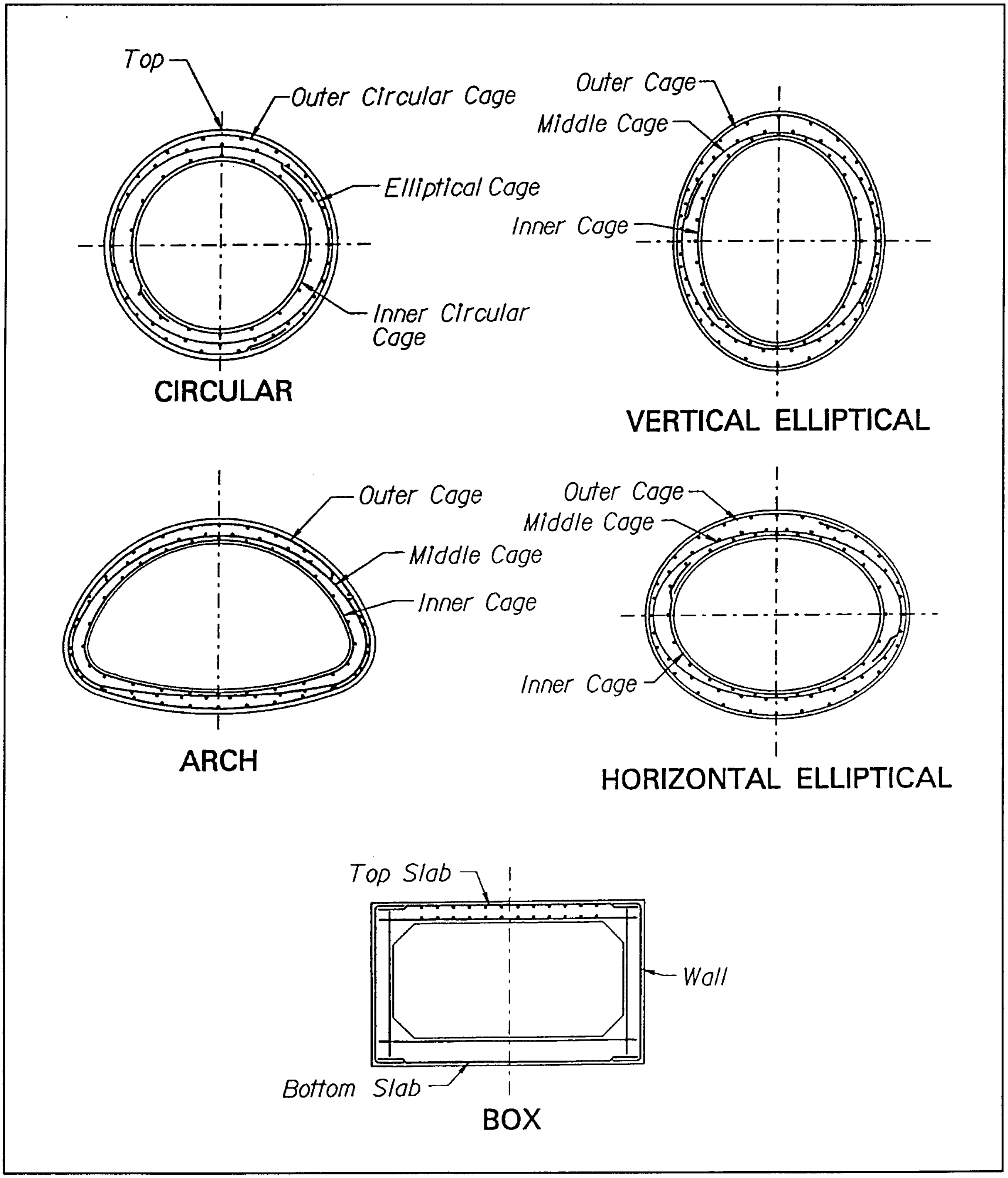
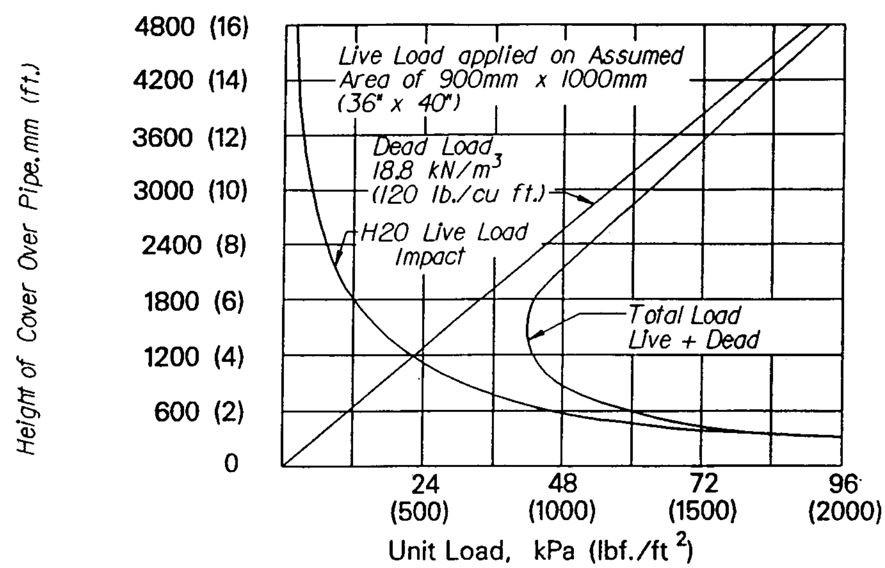
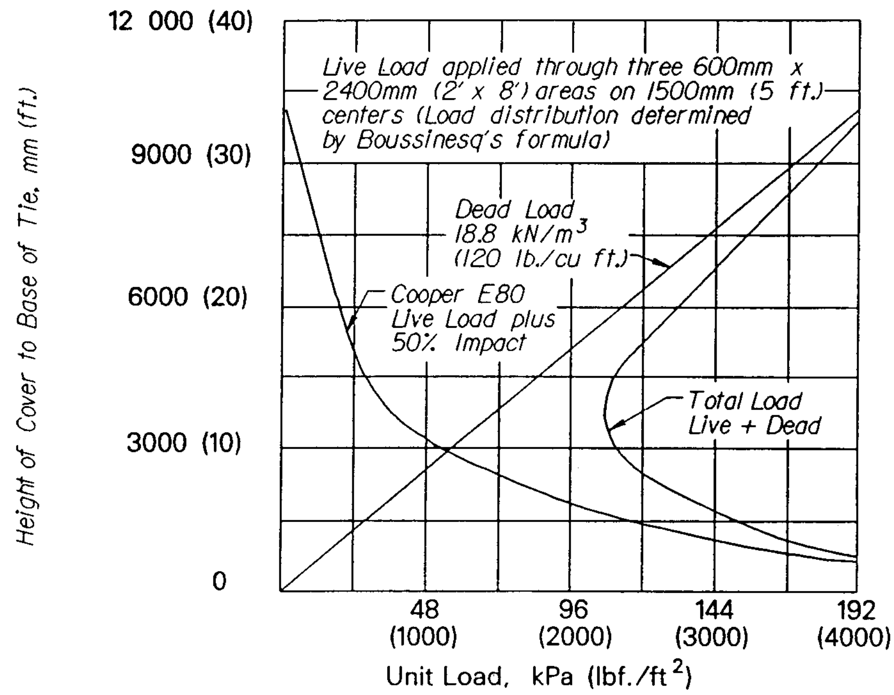


Figure 5-1. Precast culvert sections



Combined H20 highway live load and dead load is a minimum at about 1500mm (5 ft.) of cover, applied through a pavement 300mm (1 ft.) thick.



Railroad live load, Cooper E80, combined with dead load is a minimum at about 3600mm (12 ft.) Load is applied through three 600mm x 2400mm (2x8 ft.) areas on 1500mm (5 ft.) centers.

Figure 5-2. Highway and railroad loads (ASTM A 796)

Table 5-1
Materials for Reinforced Concrete Culverts

Materials	Standard	Description
Reinforced concrete circular *D-load* rated	ASTM C 76 M or AASHTO M 170 - Reinforced Concrete Culvert, Storm Drain and Sewer Pipe	Covers the use of reinforced concrete pipe for conveyance of sewage, industrial waste, storm-water drainage, and culverts for pipe with diameters from 305 to 3,660 mm (12 to 144 in.).
Reinforced concrete circular *D-load* rated tested	ASTM C 655 M or AASHTO M 242 - Reinforced Concrete D-Load Culvert, Storm Drain and Sewer Pipe	Similar to ASTM C 76 except that pipe may be accepted based on the factory *D-load* testing of nonstandard pipe classes.
Reinforced concrete arch	ASTM C 506 or AASHTO M 206 - Reinforced Concrete Arch Culvert, Storm Drain and Sewer Pipe	Covers pipe with equivalent circular diameters of 380 through 3,350 mm (15 through 132 in.).
Reinforced concrete elliptical	ASTM C 507 or AASHTO M 207 - Reinforced Concrete Elliptical Culvert, Storm Drain and Sewer Pipe	Uses classes of pipe for horizontal elliptical pipe with equivalent diameters of 450 through 3,660 mm (18 through 144 in.) and vertical elliptical pipe with equivalent diameters of 910 through 3,660 mm (36 through 144 in.).
Reinforced concrete pressure pipe	ASTM C 361 M - Reinforced Concrete Low-Head Pressure Pipe	Covers the use of pressure pipe for water heads up to 38 m (125 ft) in sizes from 305 through 2,740 mm (12 through 108 in.) in diameter.
Reinforced concrete box	ASTM C 789 M or AASHTO M 259 - Precast Reinforced Concrete Box Sections for Culverts, Storm Drains and Sewers	Covers the use of box culvert with more than 610 mm (2 ft) of earth cover over culverts that are intended for highway live loads. These sections range in size from 910-mm span by 610-mm rise (3-ft span by 2-ft rise) to a 3,050-mm span by 3,050-mm rise (10-ft span by 10-ft rise).
Reinforced concrete box less than 0.6 m (2 ft) cover HS-20	ASTM C 850 M or AASHTO M 273 - Precast Reinforced Concrete Box Section for Culverts, Storm Drains and Sewers	Applies to box sections with highway loadings with direct earth cover of less than 610 mm (2 ft). These sections range in size from a 910-mm span by 610-mm rise (3-ft span by 2-ft rise) to a 3,660-mm span by 3,660-mm rise (12-ft span by 12-ft rise).

5-5. Methods of Analysis

Wheel loads for highway HS 20 live loads may be distributed in accordance with ASTM C 857. This standard includes roof live loads, dead loads, and impact loads.

a. D-load pipe. Precast concrete sections (ASTM C 76, ASTM C 655, ASTM C 506, and ASTM C 507) are designed for *D-loads* related to the pipe class. Precast concrete sections (ASTM C 361, ASTM C 789, and ASTM C 850) are designed in accordance with the prescriptive procedures defined within the applicable ASTM. Therefore, bedding factors should be selected from Table 5-2 for trenches and calculated by using Equations 5-1 and 5-2. When the pipe is in an embankment, use Table 5-3 to calculate the load factor B_f. The value for C_c in Equation 5-2 should be taken from Figure 5-5. Use the B_f calculated by this procedure to calculate the *D-load* of the pipe. The hydraulic factor for precast concrete pipe should be one for culverts.

$$B_f = \frac{C_A}{C_N - X\,q} \tag{5-1}$$

$$q = \frac{Ap}{C_c}\left(\frac{H}{B_c} + Ep\right) \leq = 0.33 \tag{5-2}$$

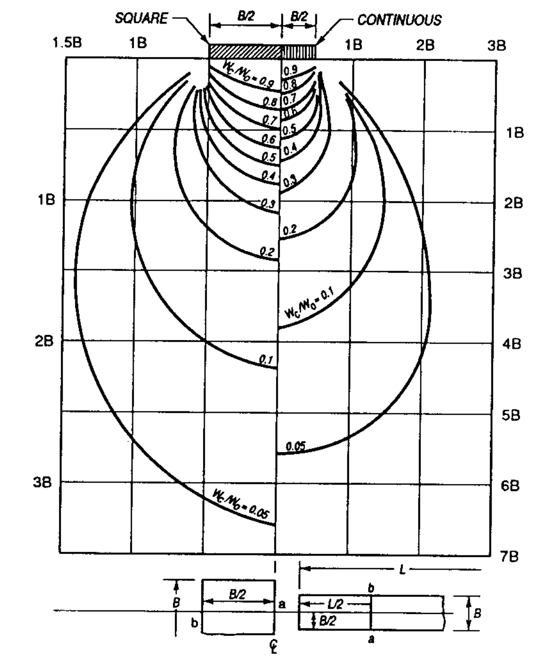
where

C_A = conduit shape constant from Table 5-3

C_N = parameter that is a function of the distribution of the vertical load and vertical reaction from Table 5-3

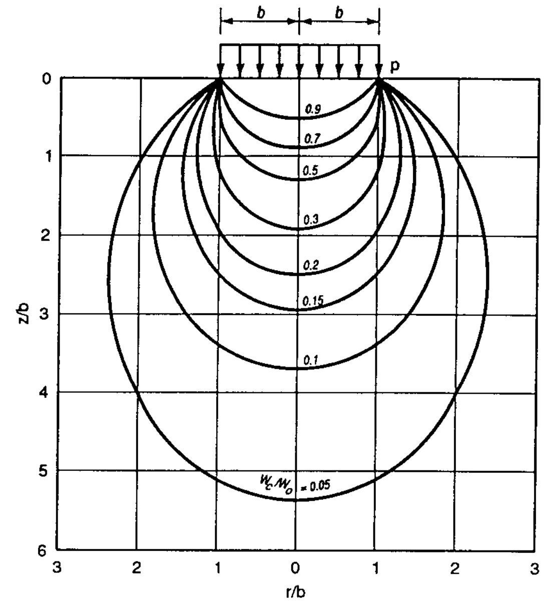
X = parameter that is a function of the area of the vertical projection of the pipe over which active lateral soil pressure is effective and is based on conduit shape from Table 5-3

A = the ratio of unit lateral soil pressure to unit vertical soil pressure based on conduit shape from Table 5-3



PRESSURE ISOBARS BASED ON THE BOUSSINESQ EQUATION FOR SQUARE AND LONG FOOTINGS. APPLICABLE ONLY ALONG LINE ab AS SHOWN.

Figure 5-3. Pressure bulb: square and continuous footings



CONTOURS OF VERTICAL NORNAL STRESS BENEATH UNIFORMLY-LOADED CIRCULAR AREA ON LINEAR ELASTIC HALF-SPACE

Figure 5-4. Pressure bulb: Circular area

p = projection ratio, the vertical distance between the outside top of the pipe and the natural ground surface, divided by the outside horizontal diameter or span of the pipe B_c

C_c = load coefficient for positive projection pipe from Figure 5-5

H = height of fill, m (ft), above top of pipe to top of fill

B_c = outside diameter or span of the conduit, m (ft)

E = load coefficient based on conduit shape from Table 5-3

q = ratio of the lateral pressure to the total vertical load

b. Box sections. Box sections are specified for the installed condition rather than a *D-load* rating, and these conditions are related to highway loadings and depth of earth cover. ASTM C 789 has standard designs for AASHTO H 20 and HS 20 loadings when the depth of fill is more than 610 mm (2 ft) or for dead load only. ASTM C 850 provides standard designs for dead loads only or in combination with AASHTO H 20 or HS 20 loadings when earth cover is less than 610 mm (2 ft).

5-6. Joints

The three types of joints used in concrete culvert construction are the O-ring gasket, the flat gasket, and the packed joint. Packed joints include mortar or mastic packing which should be used only when watertightness or joint movement is not a concern. Therefore, on culvert construction use a gasketed joint, and wrap the joint with a suitable filter fabric material to prevent soil migration into the pipe. Filter fabric requirements should be as stated in the geotechnical engineer's soils report for the project.

a. Rubber gaskets for circular pipe. ASTM C 443 M requires this joint to hold an internal or external water pressure of 90 kPa (13 psi) for straight alignments and 70 kPa (10 psi) for axially deflected alignments.

Table 5-2
Design Value Parameters for Load Factor: Trenches

Shape	Bedding	Cradle Reinforcement	Bedding Factor (B_f)
Circular (only)	A (Concrete)	A_s = 1.0%	4.8
		0.4	3.4
		0.0 (Plain Concrete)	2.8
All shapes	B (Shaped)		1.9
All shapes	C (Shaped)		1.5
Circular (only)	D (Impermissible: Flat)		1.1

Table 5-3
Design Value Parameters for Load Factor: Embankments

Shape	C_A (Shape Factor)	Bedding Class	C_N (Distribution Factor)	Projection Ratio, p	X (Lateral Projection Factor)
Circular: A = 0.33, E = 0.50					
	1.431	Class B (Shaped)	0.707	1.0	0.638
		Class C (Shaped)	0.840	0.9	0.655
				0.7	0.594
				0.5	0.423
				0.3	0.217
				0.0	0.000
Horizontal Elliptical and Arch: A = 0.23, E = 0.35					
	1.337	Class B	0.630	0.9	0.421
		Class C	0.763	0.7	0.369
				0.5	0.268
				0.3	0.148
Vertical Elliptical: A = 0.48, E = 0.73					
	1.021	Class B	0.516	0.9	0.718
		Class C	0.615	0.7	0.639
				0.5	0.457
				0.3	0.238

b. External band gaskets for noncircular pipe. ASTM C 877 applies to arch, elliptical, and box pipe sections. These sealing bands are adequate for external hydrostatic pressures of up to 90 kPa (13 psi). Joints on the installed pipe should be tested when watertightness is a concern. Sealing bands that meet this standard can be rubber and mastic or plastic film and mesh-reinforced mastic.

c. Field pipe joint testing. When watertight joints are required, one of the test methods referenced below should be used.

(1) Low-pressure air test. ASTM C 924 covers exfiltration testing of 100- to 610-mm (4- to 24-in.) concrete pipe with gasketed joints and demonstrates the condition of the pipe prior to backfilling.

(2) Infiltration/exfiltration test. ASTM C 969 covers the testing of concrete pipes up to 210 m (700 ft) in length between manholes. The infiltration test is used when the groundwater level is 1,800 mm (6 ft) above the crown of the pipe and allows a leakage including manholes of 18.5 L/(mm-diameter) (km) (24 hr) ((200 gal/(in.-diameter) (mile) (24 hr)). The exfiltration test is used when the groundwater level is 910 mm (3 ft) below the invert of the pipe and allows a leakage including manholes of 18.5 L/(mm-diameter) (km) (24 hr) ((200 gal/(in.-diameter) (mile) (24 hr)) with an average head of 0.9 m (3 ft) or less. The Corps of Engineers exfiltration test allows a leakage rate of 23.1 L/(mm-diameter) (km) (24 hr) ((250 gal/(in.-diameter) (mile) (24 hr)) for pipeline construction. This test method does not apply to water retention structures.

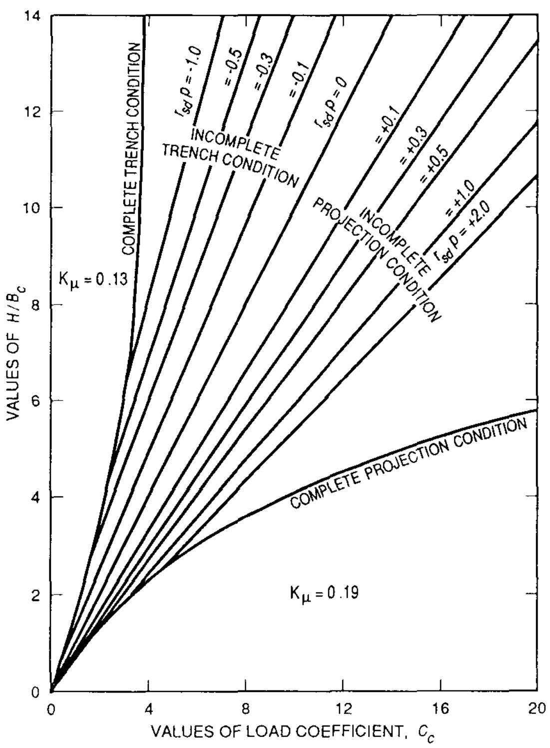


Figure 5-5. Load coefficient C_c for positive projection embankment condition

(3) Joint acceptance test. ASTM C 1103 covers the testing of joints by using air or water under low pressure to demonstrate the joint integrity of pipes with a diameter greater than 675 mm (27 in.). The internal pressure of the pipe should be maintained at 24 kPa (3.5 psi) above the design groundwater pressure of the pipe for 5 seconds. This test is used as a go/no-go test for the joint prior to backfilling the pipe.

(4) Negative air test. ASTM C 1214 covers the testing of concrete pipe with a negative air pressure for 100- to 910-mm- (4- to 36-in.-) diameter pipe using gasketed joints. Testing times and air loss vary based on pipe diameter for the pressure to drop from 177.8 to 127 mm (7 to 5 in.) of mercury.

5-7. Camber

Where considerable foundation settlement is likely to occur, camber should be used to ensure positive drainage and to accommodate the extension of the pipe due to settlement.